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Financing the Water-Energy-Food-Ecosystem Nexus project: challenges, opportunities, and pathways for sustainable investment

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The Water-Energy-Food-Ecosystem (WEFE) Nexus framework provides a holistic approach to sustainable resource management, addressing the interdependencies between these sectors to enhance resilience against climate change and resource scarcity. Despite its potential, financing WEFE projects remains a significant challenge due to complex investment structures, long-term payback periods, and difficulties in demonstrating economic returns. This paper explores innovative financing mechanisms, including climate finance, blended finance, and public-private partnerships (PPPs), which are essential for overcoming these financial barriers. It highlights the need for de-risking investment, ensuring regulatory clarity, and integrating standardized financial metrics to attract private-sector engagement. Several successful WEFE financing case studies illustrate the effectiveness of different investment approaches. The Climate Investor Two model, which combines public, private, and donor capital, has successfully supported renewable energy for irrigation, desalination, and water infrastructure projects in climate-vulnerable regions. Similarly, the Noor Ouarzazate Solar Complex in Morocco, a PPP-funded renewable energy and water efficiency project, demonstrates how government-backed risk-sharing mechanisms can mobilize large-scale private investment. Nature-based financial instruments, such as green bonds, resilience bonds, and Payment for Ecosystem Services (PES), have proven effective in promoting sustainable land management and watershed conservation. Despite these advancements, challenges such as fragmented governance, lack of standardized investment criteria, and perceived financial risks continue to hinder widespread WEFE financing. Addressing these gaps requires clear regulatory frameworks, performance-based financial incentives, and integrated risk mitigation mechanisms. This article underscores the critical role of blended finance, insurance-backed risk-sharing, and policy-driven financial incentives in ensuring long-term sustainability and scalability of WEFE projects. By strengthening financial instruments and aligning them with climate resilience and sustainability goals, WEFE investments can drive socioeconomic development while safeguarding essential ecosystem services.

KEYWORDS

Water-Energy-Food-Ecosystems Nexus, blended finance, public-private partnership, climate finance, risk mitigation

1 Introduction

The Water-Energy-Food-Ecosystem (WEFE) Nexus is an integrated approach that recognizes the interdependence of these sectors to promote sustainable resource management. It optimizes resource use by balancing trade-offs, fostering synergies, and strengthening governance. Hoff (2011) highlights its green economic growth potential, showing how it enhances water, energy, and food security by increasing efficiency, reducing trade-offs, and improving cross-sectoral governance. In an era of climate change, population growth, and resource scarcity, ensuring the sustainable and efficient use of water, energy, food, and ecosystems is vital for global stability. However, financing WEFE projects remains a significant challenge, as these initiatives require long-term investment horizons, cross-sectoral collaboration, and innovative financial models to balance economic, social, and environmental objectives. Traditional sector-based financing mechanisms often fail to capture the interconnected nature of WEFE projects, leading to fragmented investments and inefficiencies (Rhouma et al., 2024). As a result, there is an urgent need to develop innovative financial instruments, risk-sharing mechanisms, and policy frameworks that can attract public and private sector participation in WEFE initiatives.

Since the 2008 financial crisis, global water governance has shifted toward the water-energy-food-climate nexus. In 2009, UN Secretary-General urged the financial community to prioritize water security at Davos (UN-Water, 2009). The World Economic Forum (2011) later reinforced this with its report, *Water Security: The Water-Energy-Food-Climate Nexus*, linking crises in water, energy, food, and climate to structural water mismanagement.

The finance-WEFE Nexus highlights the role of global financial networks in shaping water, energy, food, and ecosystem governance by integrating sustainability into economic systems through financial instruments like credit-risk ratings. While this financialization enables investment and risk management, it also constrains sustainability goals by prioritizing economic resilience over holistic environmental outcomes (Schmidt and Matthews, 2018).

In recent years, blended finance, green bonds, and public-private partnerships (PPPs) have emerged as potential solutions to bridge the investment gap in WEFE Nexus projects (OECD, 2017; Mpakama et al., 2018; David et al., 2024; Carmona-Moreno et al., 2021; Wang and Taghizadeh-Hesary, 2023). By combining public, private, and donor funds, blended finance models help de-risk investments, making large-scale climate-resilient infrastructure more attractive to private investors (OECD, 2018). In addition, carbon markets, Payment for Ecosystem Services (PES), and resilience bonds provide alternative revenue streams for sustainable land and water management practices. However, despite the availability of these financial tools, challenges such as fragmented governance, regulatory uncertainty, high transaction costs, short-term policy focus, and limited access to credit for small-scale actors continue to hinder widespread WEFE financing.

Addressing these challenges requires a comprehensive understanding of financing mechanisms, risk mitigation strategies, and policy incentives to enhance the financial viability of WEFE projects. This paper seeks to explore the financial challenges, opportunities, and pathways for financing the WEFE Nexus by addressing the following key questions:

- What are the main challenges in financing WEFE Nexus projects, and why do traditional financial models struggle to support them?
- How can innovative financial instruments (e.g., green bonds, blended finance) be leveraged to enhance WEFE investments? How can risk financing and insurance models attract public and private investments in WEFE initiatives?
- What incentives and regulatory frameworks can encourage greater private-sector participation in WEFE financing?
- How can local and community-based financing approaches be integrated into WEFE investment strategies?
- What successful case studies demonstrate impactful WEFE financing, and what crucial lessons can be drawn from them?

By addressing these questions, this paper aims to provide practical insights and policy recommendations to enhance investment flows into WEFE projects and support long-term sustainability and resilience.

2 Methods

This study employs a multi-faceted approach to analyze the financial mechanisms, challenges, and opportunities within the Water-Energy-Food-Ecosystem (WEFE) Nexus. The methodology integrates a combination of qualitative and quantitative research techniques to ensure a comprehensive understanding of financing strategies and policy frameworks supporting sustainable investment in WEFE projects.

2.1 Literature review and theoretical framework development

We conducted a comprehensive literature review on WEFE Nexus financing. Sources included peer-reviewed journal articles, policy reports, and case studies. Notably, we examined publications from the United Nations, World Bank, European Commission, and FAO. We also reviewed academic research on blended finance, public-private partnerships (PPPs), and climate finance. Theoretical models related to risk mitigation, investment de-risking strategies, and ecosystem-based financial instruments were identified to establish a conceptual framework for analyzing WEFE financing mechanisms.

2.2 Data collection and case study analysis

The study adopts a case study approach to explore real-world applications of WEFE financing models. We selected cases based on their relevance, scalability, and effectiveness in attracting investment for integrated resource management. Notable examples include:

- Climate Investor Two (CI2): A blended finance initiative supporting renewable energy, water management, and irrigation projects in climate-vulnerable regions.
- Noor Ouarzazate Solar Complex (Morocco): A PPP model integrating solar energy and water efficiency for sustainable agriculture.
- Green Bonds and Resilience Bonds: Examined through the issuance of green finance instruments by the Asian Development Bank and the European Investment Bank to fund water, energy, and agricultural projects.
- Payment for Ecosystem Services (PES) and REDD+ projects: Evaluated to understand financial incentives for ecosystem restoration and climate resilience.

Each case study was assessed based on investment structure, funding mechanisms, risk-sharing strategies, and sustainability impact.

2.3 Policy and regulatory analysis

We conducted a detailed analysis of global, regional, and national policy frameworks to understand their influence on WEFE investment flows. The review included financial policies, green taxonomy standards, and incentive programs aimed at encouraging private sector involvement. Special attention was given to regulatory challenges such as fragmented governance, high transaction costs, and the absence of standardized financial metrics for cross-sectoral projects.

2.4 Financial instrument evaluation

Various financial instruments were examined to assess their applicability to WEFE projects. These included:

- Blended Finance: The role of public and donor funds in de-risking investment.
- Green and Blue Bonds: Their potential to raise capital for climate-resilient infrastructure.
- Carbon Markets and PES: Monetization of ecosystem services to attract impact investors.
- Insurance Mechanisms: Use of catastrophe (CAT) bonds, resilience bonds, and parametric insurance to mitigate financial risks in WEFE projects.

We conceptually evaluated financial instruments to estimate their risk-adjusted returns and long-term viability.

2.5 Stakeholder engagement and participatory approaches

To ensure inclusivity, this study examines strategies for engaging local communities, smallholder farmers, and marginalized groups in funding decisions. Best practices from community-led governance models and microfinancing initiatives were analyzed to explore how decentralized financing mechanisms can enhance WEFE Nexus project sustainability.

2.6 Comparative assessment and synthesis

The findings from literature, case studies, and financial evaluations were synthesized to identify key success factors and barriers in WEFE financing. A comparative analysis of key financing instruments relevant to the WEFE Nexus is summarized in Table 1.

This methodological approach ensures a robust, evidence-based assessment of financing pathways for the WEFE Nexus, supporting the development of integrated, scalable, and resilient investment strategies.

3 Results

3.1 Overcoming financial barriers to WEFE Nexus projects

A significant barrier to financing WEFE Nexus projects lies in the sectoral governance structures that dominate national and institutional funding allocation. Ministries and agencies responsible for water, energy, food, and ecosystem management operate within sectoral silos, each with its own budgetary processes, priorities, and institutional mandates. This fragmentation results in a lack of a dedicated champion for Nexus initiatives, leaving cross-sectoral projects without clear ownership or sustainable funding streams. Even international financing institutions, typically allocate funds within these existing sectoral structures, reinforcing sectoral boundaries rather than incentivizing integrated approaches. To effectively advance WEFE Nexus financing, it is imperative to establish inter-ministerial coordination mechanisms that transcend traditional sectoral boundaries. The formation of dedicated interdepartmental committees or technical secretariats can facilitate continuous information exchange and policy alignment among the water, energy, food, and environmental sectors. Such collaborative frameworks can enhance policy coherence, alignment toward common success indicators, and the promotion of cross-ministerial financing mechanisms.

Another challenge in financing WEFE Nexus projects is the lack of standardized financial metrics and impact assessment frameworks that accurately capture the economic, environmental, and social benefits of integrated resource management. Traditional investment evaluation models often fail to account for co-benefits and spillover effects across sectors, making it difficult to justify multi-sectoral investments. For instance, a project improving irrigation efficiency may simultaneously enhance renewable energy use, reduce ecosystem degradation, and support farmers' incomes by ensuring sustainable water access amid natural resource limitations, while also contributing to long-term food security; yet, existing financial assessment tools primarily quantify water savings without incorporating energy, biodiversity, and socio-economic benefits. Developing integrated valuation methodologies that reflect the full cost-benefit spectrum of Nexus interventions is crucial for attracting investors and policymakers. Trade-off analysis

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TABLE 1 Comparative evaluation of financing instruments for the WEFE Nexus: advantages, challenges, and applicability.

Instruments	Advantages	Disadvantages	Relevance to the WEFE Nexus	Feasibility	Scalability	Impact
Blended finance	Use of public funds to attract private investment into projects that might otherwise be too risky. Example: EIC funds (Grants + equity), Climate Investor Two	Needs careful planning to mix different funding sources. Relies on grants or low-interest loans from donors/government.	Helps mobilize big capital for multi-sector investments vital for large-scale water and energy infrastructure that also supports food systems.	High	High	High
Green bonds	Loans (bonds) specifically for environmental projects, like clean energy or water systems. Example: The Asian Development Bank has issued green bonds to finance WEFE objectives.	We must ensure the project is genuinely eco-friendly, not just labeled "green." Proper monitoring and independent verification are essential to prove real environmental benefits.	Supports clean energy, sustainable farming, and efficient water use, improving agricultural resilience and food security.	Moderate	High	Moderate–high
European Investment Bank (EIB) green bonds and sustainability loans	Provides long-term, low-interest financing for sustainable projects. Aligns with EU Green Deal and Paris Agreement goals. Supports large-scale infrastructure and innovation.	Eligibility criteria can be strict, limiting access for small-scale projects. Requires strong environmental impact assessment.	Enables financing of WEFE-related projects, such as sustainable irrigation systems, renewable energy for agriculture, and ecosystem conservation.	Moderate	High	High
Carbon Markets and Payment for Ecosystem Services (PES)	Projects earn money for reducing carbon emissions or protecting ecosystems (e.g., forests, watersheds). Example: REDD+ Projects	Carbon credit prices can change often. Must prove actual emission reductions or ecosystem services.	Protects watersheds, forests, and soils, which directly affect water supply (irrigation, drinking), agricultural productivity, and carbon storage.	Moderate	Moderate	Moderate
Resilience Bonds and Catastrophe (CAT) Bonds	Pay out when disasters (e.g., floods or droughts) occur, aiding climate adaptation in WEFE systems. Example: World Bank CAT bond	Requires specialized risk modeling (e.g., deciding when the bond pays out). Fewer investors: these structures are less common and can be harder to market.	Protects water sources and agriculture from climate shocks—vital for stable energy supply, food production, and ecosystem health.	Moderate	Moderate	High

tools (Daher and Mohtar, 2015; Halytsia et al., 2024; Rhouma et al., 2025) offer promising pathways to quantify the synergies of WEFE investments. Furthermore, advancing Environmental, Social, and Governance (ESG)-aligned reporting frameworks specific to Nexus projects could help financial institutions and investors recognize their long-term value. Without such standardized methodologies, cross-sectoral financing will continue to face barriers, limiting the scalability of Nexus-based solutions.

3.2 Financing mechanisms for WEFE Nexus projects

Multilateral organizations and climate finance institutions play a significant role in supporting WEFE Nexus projects, particularly in developing regions. Institutions such as the Green Climate Fund (GCF), Global Environment Facility (GEF), and Adaptation Fund provide grants and concessional loans to finance climate-resilient initiatives. These funds emphasize sustainable water management, renewable energy adoption, and food security, aligning well with WEFE principles. However, access to these funds requires projects to work through Accredited Entities (AEs), which can be a barrier for local project developers due to administrative complexity and strict eligibility requirements.

Blended finance presents another crucial mechanism by combining public and private capital to de-risk investments in sustainable infrastructure. This approach is particularly useful for WEFE projects that require significant upfront investment while generating long-term benefits. Instruments such as the European Fund for Sustainable Development Plus (EFSD+), Climate Investor Two, and green bonds have successfully attracted private sector participation in large-scale sustainability initiatives. By allowing concessional funding to absorb early-stage risks, blended finance makes projects more attractive to investors and ensures financial sustainability over time.

Public-Private Partnerships (PPPs) are increasingly becoming a preferred financing model for WEFE Nexus initiatives, as they share investment risks between governments and private sector entities. A notable example is the Noor Ouarzazate Solar Complex in Morocco, which integrates renewable energy production with water-efficient agriculture. Such projects demonstrate how government backing can incentivize private sector engagement, leading to scalable and sustainable WEFE solutions.

Green and blue bonds provide long-term financing by leveraging environmentally conscious investors. These financial instruments are particularly relevant for large-scale WEFE projects that incorporate climate adaptation, ecosystem restoration, and sustainable agricultural practices. The Asian Development Bank (ADB), for instance, has issued green bonds to finance water and renewable energy infrastructure, demonstrating their potential in supporting Nexus-based initiatives.

In addition to these instruments, WEFE projects that focus on ecosystem restoration and sustainable land management can generate revenue through carbon and biodiversity credits. Payment for Ecosystem Services (PES) models have been successfully applied in watershed conservation and reforestation projects, proving their viability as an alternative financing mechanism. By monetizing ecosystem benefits, these credits can attract impact investors looking for environmentally sustainable opportunities.

Despite the availability of multiple financing mechanisms, WEFE projects face significant challenges in securing funds. One major barrier is fragmented governance, as Nexus projects require coordination between multiple sectors, yet funding mechanisms often operate in silos. The long investment horizons of WEFE projects further discourage private investors, who typically seek short-term returns. Additionally, high upfront costs and uncertain revenue models create risk perceptions that limit private sector participation. The absence of standardized metrics to quantify financial and environmental impacts also reduces investor confidence, making it difficult to evaluate the true benefits of Nexus initiatives. Moreover, complex regulatory frameworks and unclear policies discourage large-scale investment in integrated projects.

3.3 Strategies to improve WEFE Nexus financing

Developing standardized investment criteria is essential to attract financing for Nexus projects. Incorporating WEFE principles into the EU Green Taxonomy, Sustainable Development Goals (SDGs), and climate finance eligibility criteria would provide a clear framework for assessing Nexus investments. In addition, enhancing risk mitigation mechanisms through guarantees, insurance products, and catastrophe bonds can help de-risk investments. Instruments such as Resilience Bonds and parametric insurance ensure quick financial relief in the event of climate-related disruptions, making Nexus projects more attractive to investors. Also, microfinancing can play a key role in supporting local-level investment by providing small-scale loans to communities and entrepreneurs involved in Nexus projects, enabling community-level participation and fostering sustainable development.

Promoting results-based financing is another effective strategy. Linking financial incentives to measurable performance outcomes, such as water savings, carbon sequestration, and agricultural productivity, enhances project viability. Sustainability-linked loans and pay-for-success models create strong incentives for integrating WEFE principles into projects. Strengthening Public-Private Partnerships (PPPs) through policy incentives and co-financing arrangements can also facilitate capital flow into sustainable WEFE initiatives. Lastly, providing technical assistance and capacity-building programs can help project developers enhance financial structuring, green bond issuance, and impact assessment, ultimately improving the bankability of Nexus projects.

3.4 Risk financing and insurance can attract public and private investment in WEFE projects

Risk financing and insurance play a critical role in reducing uncertainties associated with Water-Energy-Food-Ecosystem (WEFE) Nexus projects, making them more attractive to both public and private investors. Given the long payback periods,

climate risks, and infrastructure complexity involved in WEFE initiatives, financial mechanisms such as resilience bonds, catastrophe (CAT) bonds, and blended finance models help mitigate investment risks. One of the keyways risk financing enhances investment appeal is through structured risk-sharing mechanisms that limit potential financial losses for investors. Instruments like Resilience Bonds and CAT Bonds, as discussed in the document, provide pre-arranged payouts when specific disaster conditions—such as extreme droughts or floods—are met. This ensures that funding remains available even after environmental shocks, allowing projects to maintain operations and sustain long-term viability (World Bank, 2021).

Furthermore, parametric insurance models, which automatically pay out based on pre-defined thresholds of climate events, provide quicker financial recovery compared to traditional aid, thereby stabilizing cash flows for private investors and ensuring continuity in food, water, and energy supply chains (UNEP, 2019). Additionally, carbon markets and payments for ecosystem services (PES) offer financial returns for sustainable land and water management practices, incentivizing companies to invest in environmental conservation. Such risk-sharing frameworks enhance investor confidence, making it easier for projects to secure green bonds, concessional loans, or public-private partnerships (PPPs) to fund large-scale WEFE initiatives (European Commission, 2020).

In addition, by integrating economic instruments with innovative business models, stakeholders can identify value propositions, key resources, and partnerships that make these projects more financially viable. Examples of economic instruments include carbon pricing, which creates financial incentives for reducing emissions; subsidies and tax incentives for businesses adopting sustainable practices; green bonds, which raise capital for environmentally focused projects; and payment for ecosystem services (PES), which provides financial rewards for ecosystem protection and sustainable management. These economic instruments, along with tailored risk mitigation strategies such as insurance products and guarantees, can de-risk investments and encourage greater private sector participation. Developing business models that align user needs with sustainable outcomes can further enhance the attractiveness of these projects, ensuring long-term capital flow and successful public-private partnerships.

Beyond immediate risk coverage, insurance-backed financing mechanisms also encourage private-sector participation by ensuring long-term project sustainability and enabling innovative financial structures. Blended finance models, where public and donor funds absorb initial risks, create a pathway for private investors to engage in high-risk WEFE projects with reduced exposure. For example, the Climate Investor Two model blends public and private financing to fund desalination plants, renewable energy for irrigation, and water infrastructure in climate-vulnerable regions. Such models demonstrate that de-risking investment through insurance-backed guarantees and contingent financing attracts commercial investors who would otherwise hesitate to invest in climate-sensitive projects. Additionally, sovereign climate risk insurance schemes, where governments take the lead in securing coverage for critical water, energy, and food infrastructure, reassure investors that key national sustainability goals will be safeguarded even in extreme climate conditions (FAO, 2020). Furthermore, private investors seeking to align with ESG (Environmental, Social, and Governance) frameworks find insurance-backed WEFE projects more appealing, as they offer both financial returns and measurable sustainability outcomes. This trend has led to increased participation from institutional investors, such as pension funds and impact investment firms, who view WEFE projects as low-carbon, climate-resilient assets with long-term value. By leveraging these diverse risk financing instruments and insurance mechanisms, public and private investments in WEFE projects can be significantly scaled up, helping to secure water, food, and energy for future generations while ensuring ecosystem sustainability (UNEP, 2019).

3.5 WEFE Nexus project certification and accreditation

The WEFE Nexus project certification process provides a structured, multi-step pathway to ensure that water, energy, food, and ecosystem integration in development projects meets international sustainability and compliance standards. The process begins with project design and feasibility assessment, aligning goals with frameworks such as the UN Sustainable Development Goals (SDGs) and national climate strategies.

Once a project is conceptualized, applicable certification standards—such as ISO 14046 (water footprint), ISO 50001 (energy management), Global G.A.P (food systems), and ecosystem stewardship frameworks are identified. Ensuring regulatory compliance with environmental impact assessments, water rights, energy licenses, and food safety protocols is essential before proceeding.

This is followed by baseline data collection and monitoring, where performance indicators related to sustainability and ecosystem services are established. Technologies such as IoT sensors and GIS may be used to support real-time monitoring. An independent audit and assessment by an accredited body then verifies alignment with sustainability standards. Upon success, certification is granted, boosting credibility and access to finance.

However, certification is not static; continuous monitoring and periodic recertification (typically every 3–5 years) are required to maintain compliance and encourage ongoing improvement.

For a full breakdown of each step, associated standards, and a visual diagram of the process please refer to Supplementary material.

The WEFE Nexus accreditation process provides a structured approach to ensure that integrated projects meet international standards for sustainability, operational efficiency, and compliance. Managed by authorized accreditation units, the process typically includes pre-assessment, application submission, gap analysis, site audits, compliance reporting, and recertification (ISO, 2021; FAO, 2020; UNEP, 2019).

Projects begin by aligning with sustainability frameworks such as ISO 14046 for water footprint, ISO 50001 for energy management, GlobalG.A.P for food safety, and ecosystem-focused certifications like the Forest Stewardship Council (FSC) (FAO, 2018; ISO, 2021). Accredited units then evaluate documentation

including environmental impact assessments (EIA), resource rights, and monitoring and evaluation (M&E) plans (European Commission, 2020).

Independent on-site audits validate the project's sustainability performance, often incorporating technologies such as IoT sensors, GIS tools, and stakeholder interviews (UNEP, 2019). Upon meeting the standards, the project is awarded a formal accreditation certificate—valid for 3–5 years—and listed in sustainability registries to increase investor visibility (FAO, 2020).

To maintain accreditation, continuous monitoring, annual reporting, and periodic recertification audits are required. Non-compliance may lead to suspension or revocation (ISO, 2021).

For a detailed breakdown of each phase including audit steps, documentation, timelines, WEFE Accreditation Process Flow, please refer to Supplementary material.

3.6 Successful case studies demonstrating impactful WEFE financing and key takeaways

Several successful Water-Energy-Food-Ecosystem Nexus financing models have demonstrated how integrated resource management can drive sustainable development while attracting public and private sector investments.

3.6.1 Climate Investor Two (CI2) case study

Climate Investor Two (CI2) blended finance model, which has been instrumental in funding desalination plants, renewable energy for irrigation, and climate-resilient water infrastructure across the Global South. This financing mechanism effectively combines donor funds, public finance, and private capital, reducing investment risks and making large-scale WEFE projects bankable for commercial investors (World Bank, 2021). By de-risking investments in water-energy projects, CI2 has accelerated the adoption of solar-powered desalination and wastewater recycling facilities, particularly in climate-vulnerable regions.

While CI2 has been effective in de-risking large-scale investments, its implementation has faced notable challenges. These include complex structuring arrangements, slow disbursement timelines due to multi-stakeholder coordination, and limited availability of high-quality, investment-ready projects in certain regions. Additionally, the reliance on donor-backed guarantees can reduce long-term financial independence of local institutions. A key lesson learned is the need for early-stage technical assistance and pipeline development to ensure scalability.

3.6.2 Noor Ouarzazate Solar case study in Morocco

Another impactful case is the Noor Ouarzazate Solar Complex in Morocco, a Public-Private Partnership (PPP) that integrates solar energy and water management to support agriculture and local food production. Funded through a collaboration between the Moroccan government, World Bank, European Investment Bank (EIB), and private investors, this project demonstrates how PPP models can mobilize large-scale financing for WEFE initiatives while ensuring long-term economic and environmental sustainability (European Investment Bank, 2022). The success of Noor Ouarzazate highlights the importance of risk-sharing mechanisms in encouraging private-sector participation in large-scale energy and water projects, proving that policy alignment and regulatory clarity play a crucial role in securing financing.

Despite its success, the Noor Ouarzazate project encountered initial delays due to permitting issues and land acquisition negotiations. Coordination between multiple funding bodies required intensive project management, and energy pricing models needed to be adjusted to reflect affordability for local users. The project underscores the importance of robust governance frameworks and local stakeholder engagement to sustain complex PPPs in the WEFE domain.

3.6.3 PRIMA-funded agrovoltaic and aquaponic projects

PRIMA-funded agrovoltaic and aquaponic projects in the Mediterranean integrate solar energy with water-efficient agricultural practices to optimize resource use. These projects have demonstrated that multi-functional infrastructure investments can increase resilience to climate change while enhancing food production and reducing environmental footprints. Agrovoltaics, which involve growing crops beneath solar panels, maximize land use efficiency while reducing water evaporation and promoting clean energy production. Similarly, aquaponic systems create a closed-loop water and nutrient cycle, improving agricultural productivity without overexploiting freshwater resources.

These decentralized models offer promising outcomes, yet they also face scale-up limitations. Key constraints include high upfront costs for integrated technologies, limited technical capacity among local operators, and insufficient policy incentives for smallholder adoption. Lessons learned emphasize the value of piloting low-cost models, strengthening training programs, and aligning subsidies or credits with climate-smart agriculture initiatives.

3.6.4 REDD+ and PES case study

Another successful case is the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiative, where carbon finance mechanisms are used to fund ecosystem protection while generating economic benefits for local communities. By linking forest conservation to carbon markets and Payments for Ecosystem Services (PES), REDD+ projects provide financial incentives for landowners and indigenous communities to maintain ecosystem services, thus ensuring long-term financial sustainability for WEFE-related investments (UNEP, 2019). The key takeaways from these case studies are clear: blended finance models, nature-based solutions, public-private partnerships, and carbon finance mechanisms are all crucial in scaling up sustainable WEFE projects. Furthermore, success is dependent on inclusive governance, risk-sharing mechanisms, and regulatory support, which ensure that both investors and local communities benefit from these projects while achieving long-term environmental and economic resilience.

Although REDD+ programs have generated measurable benefits, they often struggle with inconsistent carbon pricing, challenges in verifying ecosystem service outcomes, and risks of displacing agricultural activities. Additionally, ensuring equitable distribution of financial benefits to indigenous and local communities remains an ongoing governance challenge. These insights suggest that integrating strong social safeguards and monitoring protocols is essential for long-term viability.

3.7 Engagement of local and marginalized communities in shaping funding decisions

Ensuring meaningful participation of local and marginalized communities in funding decisions for Water-Energy-Food-Ecosystem (WEFE) projects requires inclusive governance structures, transparent financial mechanisms, and participatory decision-making. One of the most effective ways to involve these communities is through early-stage engagement, where local stakeholders are consulted before financial allocations and project designs are finalized. Participatory approaches, such as community meetings, focus groups, and multi-stakeholder dialogues, help capture local needs and concerns, ensuring that projects are socially relevant and context-specific (FAO, 2020). Additionally, empowering communities with financial literacy training and project management skills enables them to contribute actively to funding decisions rather than being passive beneficiaries. By equipping them with the ability to assess project budgets, negotiate terms, and evaluate trade-offs, marginalized groups can advocate for equitable resource distribution and prevent elite capture of funds (UNDP, 2021). Microfinancing can play a critical role in this process by providing small-scale loans to local entrepreneurs and communities, thus facilitating local-level investments and strengthening financial independence. It enables local actors to directly invest in and benefit from WEFE projects, fostering local ownership and sustainable development. Microfinance mechanisms can empower communities to engage more effectively in Nexus projects, addressing both financial and social barriers while enhancing the project's sustainability outcomes.

Furthermore, integrating Traditional Ecological Knowledge (TEK) into funding decisions ensures that indigenous and local wisdom informs sustainable water, energy, and food management strategies, making projects more resilient and community-driven. Governments and international donors must also commit to allocating a percentage of WEFE project funds specifically for community-led initiatives, allowing local cooperatives and grassroots organizations to design and implement micro-projects that align with larger WEFE goals (European Commission, 2022). Without such intentional allocations, funding decisions risk being dominated by external actors, leaving local populations without a genuine stake in the process.

Transparency and inclusive governance mechanisms are crucial in preventing marginalization in WEFE project financing. Publicly accessible budgets, regular financial updates, and open forums for discussion build trust between local communities and funding agencies, ensuring that financial decisions reflect local priorities rather than external interests (UNEP, 2021). One effective approach is the establishment of Community Advisory Boards (CABs) that include designated representatives from marginalized groups—such as women, indigenous peoples, smallholder farmers, and youth—who hold voting power in funding allocations (World Bank, 2020). This ensures that funding structures reflect diverse socio-economic needs, preventing wealthier or politically connected actors from disproportionately benefiting. Additionally, introducing social audits and participatory budgeting models—where communities directly oversee expenditure and project progress—can reduce corruption and inefficiencies in fund utilization. Case studies from PRIMA-funded WEFE projects in the Mediterranean highlight that projects which incorporate co-decision mechanisms—where community members have direct say in financial prioritization—see higher acceptance rates, increased long-term sustainability, and stronger local ownership. Finally, leveraging technology-driven solutions—such as mobile-based financial tracking apps, community radio updates, and blockchain-enabled transparency platforms—ensures that even remote or illiterate populations remain informed and engaged in funding decisions. By embedding equity, transparency, and accountability into WEFE financing frameworks, local and marginalized communities can shift from being recipients of externally dictated projects to active architects of sustainable development in their regions.

3.8 Incentives and regulations that drive private-sector participation in WEFE efforts

To encourage private-sector participation in Water-Energy-Food-Ecosystem (WEFE) Nexus projects, governments and international institutions must implement a combination of financial incentives, regulatory frameworks, and risk-reduction mechanisms that make investments in these projects more attractive. One of the most effective incentives is the provision of targeted subsidies and tax incentives for businesses that adopt sustainable WEFE practices. For example, subsidies for agroecology, water-saving irrigation systems, and renewable energy in agriculture help reduce the initial capital costs for companies, making sustainability more financially viable (FAO, 2020). Additionally, low-interest green loans and sustainability-linked credit provide businesses with affordable financing options for water-efficient technologies, solar-powered irrigation, and circular economy projects (World Bank, 2021). Governments can also implement Resource-Saving Credit Systems, where businesses earn tradeable credits for reducing water consumption, energy use, and carbon emissions, which can then be sold or offset against environmental compliance requirements (European Commission, 2022). The integration of these credit systems can enhance the effectiveness of environmental policies by aligning economic incentives with long-term sustainability goals, fostering greater private sector participation in environmental conservation (Liu et al., 2025). Another important financial tool is the Payment for Ecosystem Services (PES) model, where companies receive financial compensation for investing in forest conservation, watershed protection, and sustainable land-use practices. This not only aligns business interests with environmental sustainability but

also creates a market-driven incentive for long-term private-sector engagement (UNEP, 2019).

In addition to financial incentives, strong regulatory frameworks play a crucial role in driving private-sector investment in WEFE Nexus projects by ensuring clear guidelines, risk reduction, and long-term policy stability. For instance, governments can introduce mandatory water efficiency standards, carbon reduction targets, and circular economy policies that push businesses toward sustainable resource management while also rewarding early adopters with preferential contracts or market access. Regulatory frameworks such as mandatory corporate reporting on environmental, social, and governance (ESG) metrics encourage companies to integrate WEFE principles into their business models, making sustainable investments a competitive advantage.

Furthermore, carbon pricing mechanisms, such as cap-and-trade systems and carbon taxes, incentivize businesses to reduce emissions while creating a financial market for carbon credits, which can be reinvested in WEFE-aligned projects (UNEP, 2019). By implementing a balanced mix of incentives and regulations, governments can transform WEFE Nexus initiatives into financially viable, low-risk, and high-impact investment opportunities, ultimately driving long-term private-sector engagement in sustainable development.

4 Discussion

The findings of this study highlight the critical financial challenges and opportunities in scaling up investments in Water-Energy-Food-Ecosystem Nexus projects. While innovative financial instruments such as blended finance, green bonds, and public-private partnerships (PPPs) have demonstrated success in mobilizing investment, key barriers remain, including fragmented governance, high transaction costs, and a lack of standardized financial metrics. These issues limit the ability of investors to assess the economic and environmental benefits of integrated resource management, thereby discouraging large-scale private sector participation.

A significant challenge in financing WEFE projects is the dominance of sectoral governance structures, where ministries and agencies responsible for water, energy, food, and ecosystem management operate in silos. This fragmentation results in limited coordination, misaligned funding priorities, and a lack of dedicated champions for Nexus initiatives. Even international financing institutions tend to allocate funds within existing sectoral structures, further reinforcing these barriers. To address this, the study suggests the establishment of inter-ministerial coordination mechanisms, such as technical secretariats, to facilitate information exchange and policy alignment. Creating cross-sectoral investment frameworks can enhance coherence and enable more effective resource mobilization.

Another key finding relates to the limited availability of standardized investment criteria and impact assessment methodologies for WEFE projects. Traditional financial assessment tools often fail to capture the full range of economic, social, and environmental benefits that arise from integrated resource management. For example, an irrigation efficiency project may simultaneously enhance renewable energy use, reduce ecosystem degradation, and support farmers' incomes, yet existing financial models primarily quantify water savings without accounting for these broader co-benefits. Developing integrated valuation methodologies and aligning financial reporting frameworks with ESG (Environmental, Social, and Governance) principles could improve investor confidence and encourage financing for cross-sectoral projects.

Despite these challenges, the study finds that multilateral institutions and climate finance mechanisms play a crucial role in supporting WEFE Nexus projects, particularly in developing regions. Entities such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF) provide concessional financing for climate-resilient projects, but access to these funds remains complex due to administrative burdens and eligibility restrictions. Expanding access to such financing through capacity-building programs and simplified application processes could enhance the participation of local and community-based actors in WEFE investments.

Blended finance emerged as one of the most effective mechanisms for reducing investment risks and attracting private sector capital (OECD, 2018). The study highlights successful examples such as the Climate Investor Two model, which combines public, private, and donor capital to fund climate-resilient infrastructure. Similarly, green bonds and resilience bonds issued by institutions such as the Asian Development Bank (ADB) have provided crucial funding for sustainable water, energy, and food projects. These financing models demonstrate that public sector involvement in de-risking investment—whether through guarantees, concessional loans, or insurance-backed mechanisms—is key to enhancing the financial viability of WEFE projects.

Public-private partnerships (PPPs) have proven successful in large-scale WEFE projects, such as the Noor Ouarzazate Solar Complex in Morocco, demonstrating that clear risk-sharing mechanisms and government-backed financial incentives can unlock substantial private capital. In many regions, Public-Private Partnerships (PPPs) have been successful in leveraging private-sector expertise and capital to develop large-scale WEFE infrastructure, such as desalination plants, renewable energy grids, and climate-smart agriculture projects (World Bank, 2020). For example, the Noor Ouarzazate Solar Complex in Morocco, a PPP-financed renewable energy and water efficiency project, demonstrates how clear regulations and risk-sharing mechanisms can attract large-scale private investment in the WEFE space (European Investment Bank, 2022). Multiple studies highlight public-private partnerships as a preferred approach for implementing WEFE projects (FAO, 2022; Markantonis et al., 2019; Mayor Rodríguez, 2016). These inclusive solutions are especially effective in diverse and fragmented regions like the Mediterranean, where engaging local actors is crucial to addressing specific needs.

The study also underscores the importance of incorporating risk financing and insurance instruments, such as catastrophe bonds and parametric insurance, to attract investment into climate-sensitive WEFE initiatives. Risk-sharing frameworks not only enhance financial stability but also ensure continuity of services in the face of environmental shocks. Additionally, linking WEFE projects to carbon markets and Payments for Ecosystem

Services (PES) could provide alternative revenue streams, making projects more attractive to impact investors and sustainability-focused funds.

An important aspect of WEFE financing is the engagement of local and marginalized communities in decision-making. The study finds that participatory governance models, microfinancing, and community-led investment strategies contribute to project acceptance and long-term sustainability. Ensuring transparency in financial flows and establishing mechanisms such as Community Advisory Boards (CABs) can prevent resource capture by elite groups and ensure that investments align with local priorities. Digital solutions, including mobile financial tracking applications and blockchain-enabled transparency tools, could further enhance accountability and inclusivity in WEFE financing.

The present study highlights the need for strong regulatory and policy support to drive private-sector investment in WEFE Nexus projects. Governments can play a pivotal role by introducing tax incentives, resource-saving credit systems, and sustainability-linked loan mechanisms to encourage businesses to adopt WEFE-aligned practices. Regulatory clarity, particularly in areas such as water rights, energy tariffs, and environmental impact assessments, is essential for creating a stable investment environment.

4.1 Political, social, and governance barriers in WEFE financing

Despite the availability of innovative financial instruments and investment models, political, social, and governance challenges continue to hinder the effective financing and implementation of WEFE Nexus projects. One major barrier is the fragmentation of institutional responsibilities across the water, energy, food, and ecosystem sectors. Ministries and agencies often operate in silos, with separate planning cycles, regulations, and budget allocations. This lack of inter-ministerial coordination leads to inefficiencies and missed opportunities for integrated project development.

In addition, governance systems frequently lack mechanisms for inclusive decision-making, limiting the participation of local communities, marginalized groups, and indigenous populations in financing discussions. Without meaningful engagement, projects risk failing to reflect local needs, reducing their long-term sustainability and social legitimacy.

Regulatory uncertainty also plays a key role. Many countries lack clear legal frameworks for cross-sectoral investments, making it difficult for private sector actors to evaluate and manage risk. Unclear water rights, energy tariffs, and environmental permitting procedures introduce additional layers of complexity that discourage investment.

Moreover, short-term political agendas often conflict with the long-term nature of WEFE investments. Frequent changes in government priorities can disrupt project continuity and erode investor confidence. Addressing these challenges requires not only financial innovation but also the strengthening of governance systems. Key strategies include establishing intersectoral coordination bodies, improving regulatory clarity, and institutionalizing community-led planning approaches. These measures are essential to create an enabling environment that can attract sustained, inclusive investment into WEFE Nexus solutions.

5 Conclusion

The Water-Energy-Food-Ecosystem (WEFE) Nexus presents a transformative approach to sustainable resource management, offering opportunities for economic growth, enhanced resilience, and improved cross-sectoral integration. However, financing WEFE projects remains a major challenge, primarily due to the complexity of investment structures, long-term payback periods, and the difficulties in demonstrating direct economic returns. Overcoming these barriers requires a paradigm shift in investment strategies, leveraging innovative financing mechanisms such as blended finance, climate finance, green bonds, and public-private partnerships (PPPs) to de-risk investments and attract private sector engagement.

Key challenges persist, including fragmented governance, a lack of standardized investment criteria, and limited financial instruments tailored to cross-sectoral projects. Addressing these issues demands clear regulatory frameworks, integrated risk mitigation strategies, and performance-based financial incentives that align investor interests with long-term sustainability goals. Insurance-backed risk-sharing mechanisms and resilience bonds also play a crucial role in ensuring financial stability for WEFE projects, particularly in climate-vulnerable regions.

Aligning financial instruments with climate resilience and sustainability goals is imperative to scale up WEFE investments. By integrating economic valuation frameworks, ESG-aligned financial reporting, and ecosystem-based financial instruments, investors can better assess the long-term benefits of WEFE projects. Additionally, policy-driven incentives—such as tax benefits for sustainable infrastructure, resource-saving credit systems, and Payments for Ecosystem Services (PES)—can further enhance financial viability and encourage greater private-sector participation.

Looking ahead, further research and policy development will be crucial in refining WEFE financing strategies. The continuous evolution of innovative financial tools, impact measurement methodologies, and digital solutions (such as blockchain for transparent financing and AI-driven risk assessment) will help bridge existing investment gaps. Collaborative efforts among governments, financial institutions, private investors, and local communities will be essential to driving sustainable financing for the Nexus, ensuring that investments contribute not only to economic returns but also to climate resilience, food security, and ecosystem preservation.

By strengthening financial instruments and fostering cross-sectoral collaboration, the WEFE Nexus can serve as a cornerstone for achieving long-term sustainability, enhancing resource efficiency, and securing the livelihoods of future generations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AR: Writing – original draft. BD: Writing – review & editing. MV: Writing – review & editing. RM: Validation, Writing – review & editing. GM: Supervision, Validation, Writing – review & editing.

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Supplementary material

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